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# Estimating Wind and Wave Induced Forces On a Floating Wind Turbine

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## Abstract

In this work, the basic model for a spar buoy floating wind turbine [1], used by an extended Kalman filter, is presented and results concerning wind speed and wave force estimations are shown. The wind speed and aerodynamic forces are estimated using an extended Kalman filter based on a first-principles derived state space model of the floating wind turbine.

The ability to estimate aero- and hydrodynamic states could prove crucial for the performance of model-based control methods applied on floating wind turbines.

Furthermore, two types of water kinematics have been compared to determine whether or not linear and nonlinear water kinematics lead to significantly different loads.

## Objectives

To investigate whether linear and nonlinear water kinematics lead to significantly different loads.

To demonstrate the ability of an extended Kalman filter based on a *first principles model* to estimate both wave and wind induced forces.

## Methods

### Model used by the EKF

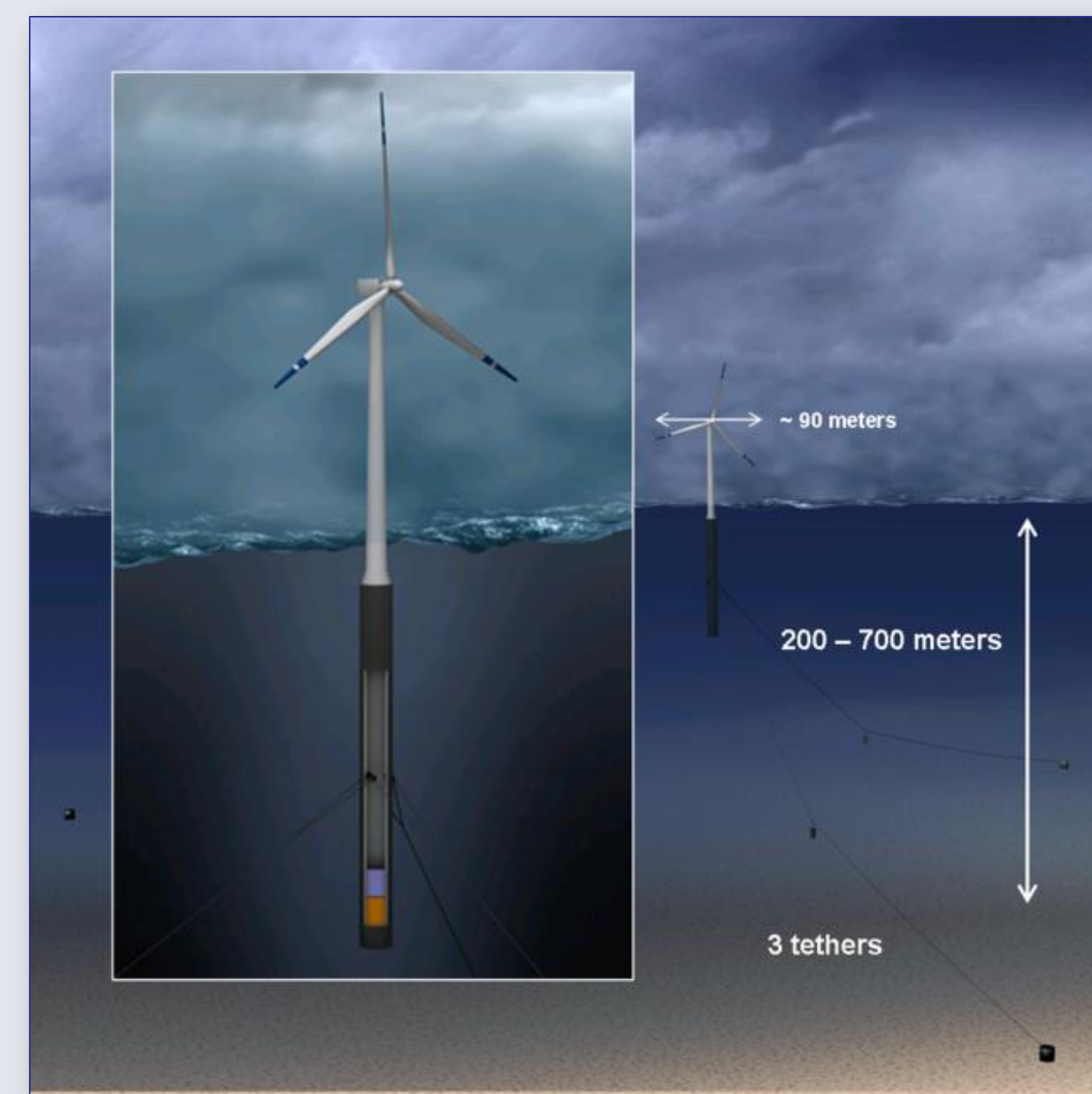
The *first principles model* used by the extended Kalman filter (EKF) includes the following states:

#### Wind turbine states

- 1 or 2 tower fore-aft DOF
- 1 or 2 tower side-side DOF
- 2 blade edge-wise DOF pr. blade
- 2 blade flap-wise DOF pr. blade
- 1 induced wind speed state pr. blade

#### Disturbance states

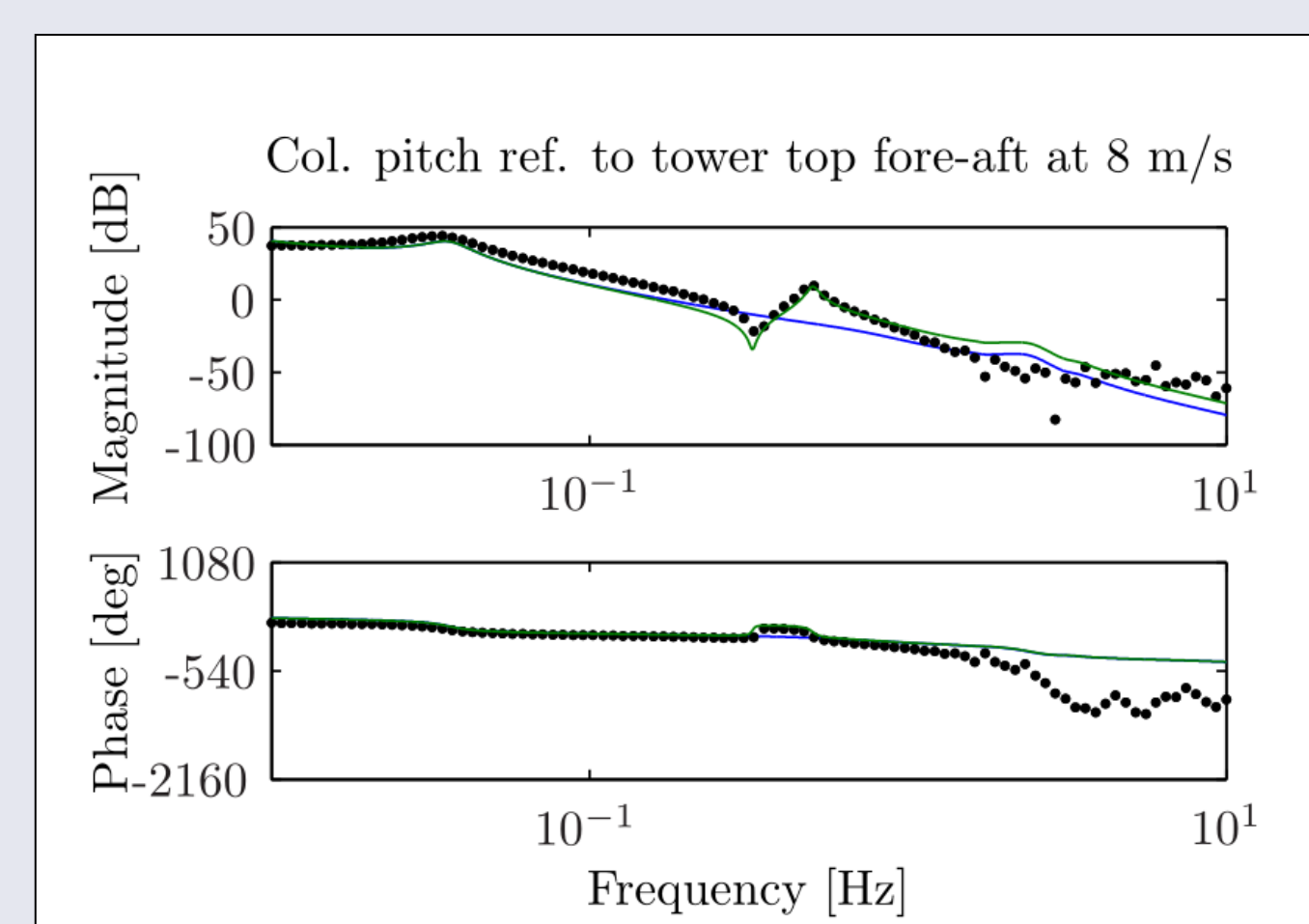
- 1 wind speed (2<sup>nd</sup> order) pr. blade
- 1 fore-aft hydrodynamic force (2<sup>nd</sup> order)
- 1 side-side hydrodynamic force (2<sup>nd</sup> order)



### Sensors used by the EKF

The extended Kalman filter relies on the following sensors to estimate the states of the model:

- Pitch angles of each blade
- Electro magnetic generator torque
- Generator power
- Generator speed
- Rotor speed
- Tower top fore-aft acceleration
- Tower top side-side acceleration
- Flap-wise blade root bending moment at each blade
- Edge-wise blade root bending moment at each blade



### Multi-blade coordinate transformation

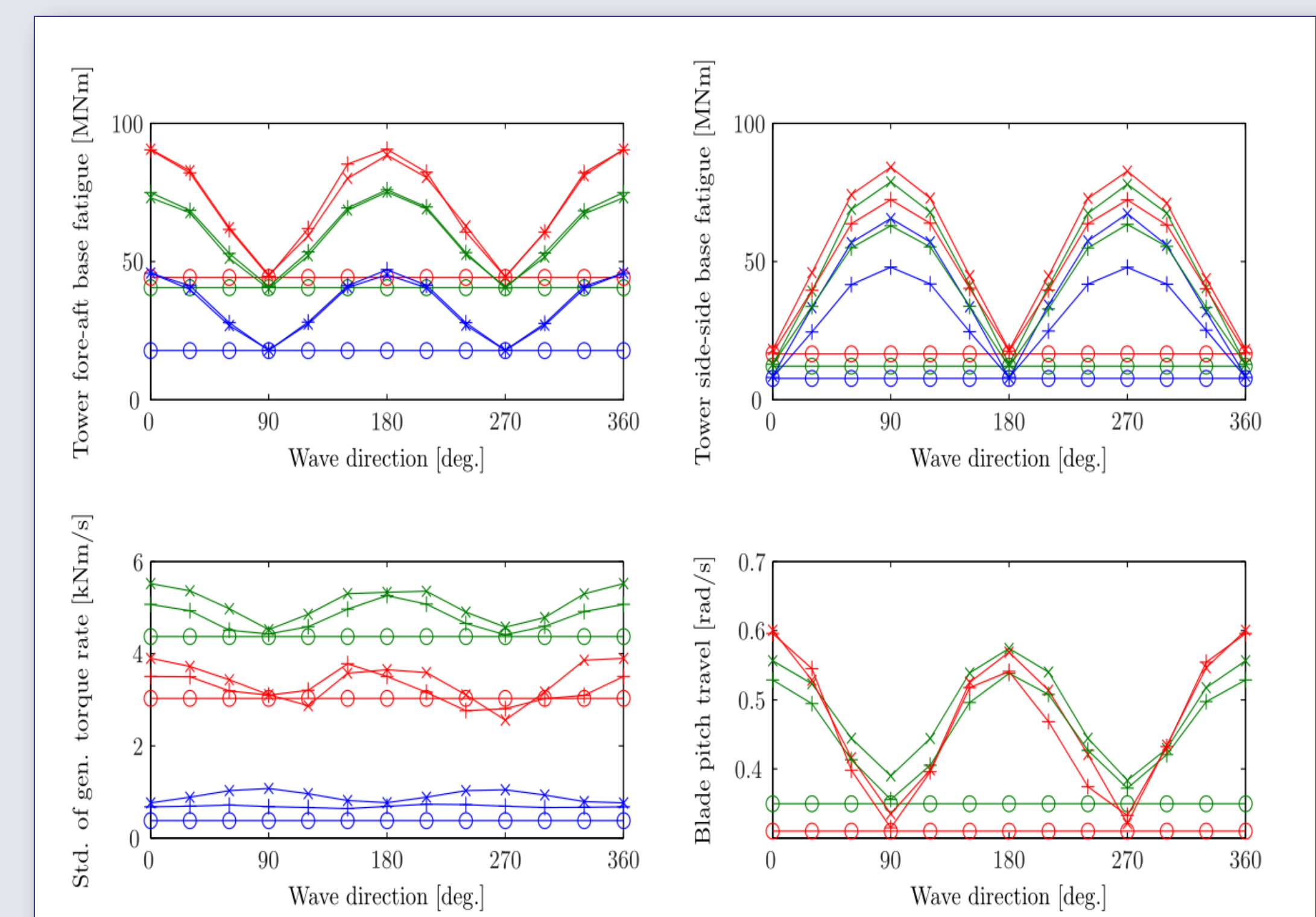
The model employs the multi-blade coordinate transformation to turn the time varying wind turbine model into a time invariant system.

## Results

### Simulations

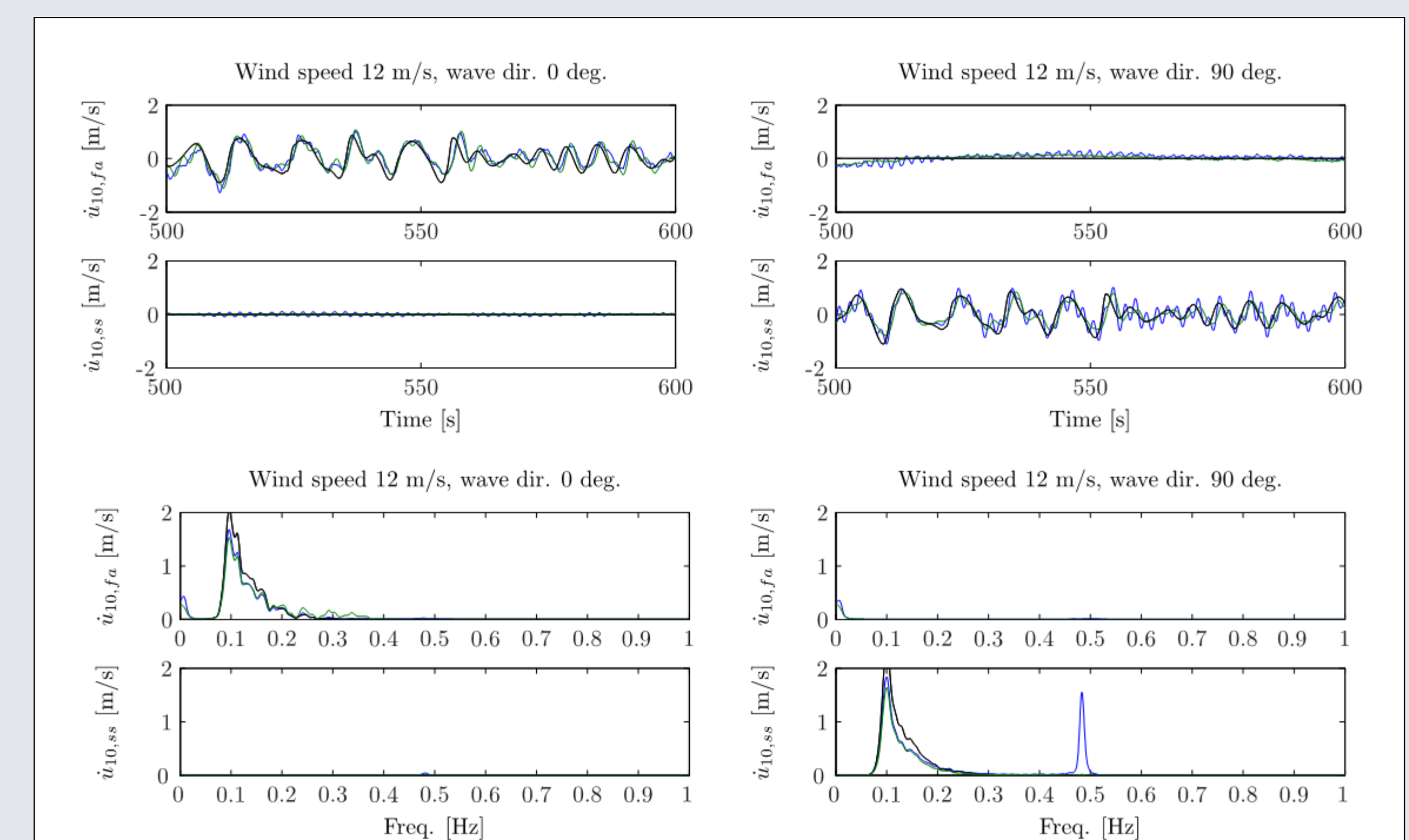
The simulations are performed in the high fidelity hydro-aero-servo-elastic software HAWC2 [2]. IEC class A turbulence at mean wind speeds of 6 m/s, 12 m/s and 18 m/s are used. The water kinematics are based on a water surface elevation given by JONSWAP spectral function with significant heights of 4 m, 6.4 m and 8 m for the before mentioned mean wind speeds. The wind turbine parameters and controller are based on [3].

### Water kinematic and wave direction dependents loads



**Fig. 1:** Performance metrics at different wave incidence angle for three different wind speeds 6 m/s, 12 m/s and 18 m/s plotted with blue, green and red lines, respectively. (o) No waves, (x) Linear irregular Airy with Wheeler stretching, (+) Nonlinear.

### Hydro force estimation



**Fig 2:** Estimation of hydrodynamic forces. Black line depicts the real water acceleration at 10 m depth. Blue and green lines depicts estimated hydrodynamic force by EKF based on models with one and two tower modes in each direction, respectively. Upper figures depicts time series and lower figures depicts power spectrum density.

## Conclusions

The presented investigation is not able to draw any conclusion regarding whether or not nonlinear water kinematics provide significantly different loads compared to linear water kinematics for the particular setup.

The presented EKF is able to estimate the hydrodynamic forces affecting the floating wind turbine, mainly caused by water acceleration. If the second elastics tower mode is omitted from the model used by the EKF, the estimated hydrodynamic forces will contain a significant contributions from the omitted tower mode.

## References

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3. J. Jonkman. Dynamics modeling and loads analysis of an offshore floating wind turbine. Technical Report NREL/TP-500-41958, National Renewable Energy Laboratory, 1617 Cole Boulevard, Golden, Colorado 80401-3393, November 2007.